Health and the Evolution of Welfare across Brazilian Municipalities*

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Abstract

This paper describes the pattern of reductions in mortality across Brazilian municipalities between 1970 and 2000, and analyzes its causes and consequences. It shows that, as in the international context, the relationship between income and life expectancy has shifted consistently in the recent past. We use a compensating differentials approach to estimate the value of the observed reductions in mortality. The results suggest that gains in life expectancy had a welfare value equivalent to 39% of the growth in income per capita, being therefore responsible for 28% of the overall improvement in welfare. We then use a dynamic panel to estimate the determinants of these gains. We show that 71% of the within municipality variation in mortality can be explained by changes in income per capita (33%), access to water (16%), illiteracy (16%), and sanitation (6%). Education and public health infrastructure appear as key determinants of the changes in life expectancy not explained by income.

Resumo

Este artigo descreve o padrão de redução de mortalidade entre municípios brasileiros entre 1970 e 2000, e discute suas causas e conseqüências. O trabalho mostra que, assim como no contexto internacional, a relação entre renda per capita e esperança de vida tem se deslocado consistentemente no passado recente. Usamos uma abordagem de diferenciais compensatórios para estimar o valor monetário das mudanças nas taxas de mortalidade. Os resultados sugerem que os de aumentos na esperança de vida representaram ganhos de bem estar equivalentes a 39% do aumento de renda observado no período, sendo assim responsáveis por 28% dos ganhos totais de bem-estar. Em seguida, usamos um painel dinâmico para estimar os determinantes dessas mudanças. Mostramos que 71% da variação de mortalidade dentro de municípios (*within*) pode ser explicada por mudanças na renda per capita (33%), acesso a água tratada (16%), alfabetização (16%) e saneamento básico (6%). Educação e infra-estrutura de saúde pública aparecem como determinantes importantes das mudanças em mortalidade não explicadas por aumentos na renda per capita.

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1 Introduction

This paper analyzes the causes and consequences of improvements in life expectancy across Brazilian municipalities between 1970 and 2000. We use a compensating differentials approach to give monetary values to life expectancy gains, and compare these gains to the evolution of income. Mortality reductions in the period had a welfare value equivalent to an increase of $1,800 in yearly income (1996 international prices), and therefore were responsible for 28% of the overall improvements in welfare. We show that most of the welfare gains from life expectancy can be attributed to improved access to treated water and sanitation, and reductions in illiteracy rates. Together with income, these variables explain 71% of the within municipality variation in life expectancy in Brazil. Nevertheless, in contrast to cross-country evidence (Bourguignon and Morrison, 2004 and Becker et al, 2005), reductions in mortality did not contribute to reduce overall welfare inequality.

Brazil experienced significant improvements in health in recent decades. Between 1960 and 2000, infant mortality rate before age 1 was reduced from 115 to 32 (per 1,000 live births), while life expectancy at birth increased from 55 to 68 years (World Bank, 2005). At the same time, income per capita measured in constant prices increased by roughly 190% (Penn World Tables 6.1). Though income was partially responsible for the improvements in health, amounting evidence suggests that a significant portion of recent changes in life expectancy across the developing world has been orthogonal to changes in income (Preston, 1975 and 1980, Becker et al, 2005, and Deaton, 2005, among others). Therefore, if life expectancy is a relevant dimension of welfare, its explicit incorporation in the evaluation of changes in well-being in Brazil, and the understanding of its determinants, become very important questions. Recent estimates suggest that longevity has indeed been a quantitatively important component of the overall gains in welfare during the twentieth century, both within and across countries.[1]

This paper looks at the extent and variation of life expectancy gains between 1970 and 2000 across Brazilian municipalities. We show that, as in the international context, there has been a consistent shift in the relationship between income and life expectancy at birth. For constant levels of income, gains in life expectancy in this thirty-year interval have been typically above 5 years. Nevertheless, the pattern and evolution of life expectancy inequality across Brazilian municipalities has been quite different from that observed across countries. The income gradient of life expectancy is less steep across Brazilian municipalities than across countries. In addition, gains in life expectancy have been more homogeneously distributed within Brazil than across countries, so that poorer areas did not gain as much in relation to rich areas as poor countries did in relation to rich countries. Both these patterns are consistent with the idea that part of the relation between income and life expectancy across countries reflects provision of public health infrastructure and services, which tends to be more homogeneous within countries. Nevertheless, this also implies that the inequality reducing role of life expectancy noticed in the cross-country context should not be as relevant across different regions of the same country.

In order to estimate the welfare implications of the extent and pattern of changes in life expectancy, we use a hypothetical life-cycle individual set up (Becker et al, 2005). Using the concept of compensating differentials, we estimate the monetary value of the gains in life expectancy observed in the period and evaluate their relative importance in terms of the overall gains in welfare. For our representative individual, reductions in mortality had a value corresponding to an increase of $1,800 in annual income, or 39% of the observed growth in income per capita. Nevertheless, given the profile of changes described before, mortality reductions did not contribute much to change overall welfare inequality, even though inequality in life expectancy itself was reduced. This was possible because the higher value attributed to mortality reductions by wealthier individuals was more than enough to compensate for the smaller gains they experienced.

Finally, we use a panel of 3,952 municipalities between 1970 and 2000 to estimate the role of public health infrastructure and education in determining the changes in life expectancy. The homogeneity of mortality reductions across Brazilian municipalities suggests that changes in the

[1] See Cutler and Richardson (1997), Nordhaus (2003), and Murphy and Topel (2003) for US studies. Burström et al (2003) look at the case of Sweden and García-Verdú (2005) looks at the case of Mexico. Becker et al (2005) analyze the impact of life expectancy on the evolution of welfare inequality across countries.

provision of public goods may have been an important factor. We concentrate on the role of public health infrastructure and education because these are dimensions over which significant improvements have been registered. For example, according to our dataset (to be presented in the next section), the fraction of households with access to treated water connected to the public water system increased from 15% in 1970 to 63% in 2000, while illiteracy rates were reduced from 44% to 21%. We use the dynamic panel techniques developed by Arellano and Bond (1991) to evaluate the roles of education, provision of clean water, and sanitation. The technique allows us to take into account the simultaneous determination of the endogenous and exogenous variables, and the dependency of health outcomes on the accumulation of health human capital through previous use of health inputs. The results indicate that a fifty percentage point increase in the fraction of households with access to treated water is associated with a 2.5 year gain in life expectancy at birth, while the same increase in the fraction of households with access to sanitation is associated with a 1.4 year gain. A reduction of fifty percentage points in illiteracy rates, on its turn, is associated with an increase of 5.4 years in life expectancy at birth. Changes in these three variables explain 38% of the within municipality variation in life expectancy in the sample (16% attributed to improved access to water, 6% to improved sanitation, and 16% to reductions in illiteracy rates), or 51% of the overall variation. These three variables, together with income per capita, explain 71% of the variation in life expectancy within municipalities, or 93% of the overall variation. For our representative individual, this implies that changes in access to water and illiteracy rates between 1970 and 2000 had a lifetime value of $7,500 each, only taking into account their effects on mortality. The equivalent number for improved sanitation was $2,800.

The paper contributes to the literature on health and development in two ways. First, we bring the discussion on the welfare value of health improvements – which has been mostly restricted to developed countries (see footnote 1) – to a developing country context. We show that the share of welfare gains due to health improvements in Brazil has been larger than that typically observed in developed countries. Nevertheless, in contrast to international trends, health improvements have not contributed to reduce overall welfare disparities within Brazil. Second, we add to the literature on the determinants of mortality reductions in the developing world (Preston, 1975 and 1980, Palloni and Wyrick, 1981, and Becker et al 2005). A large part of the gains in life expectancy in developing countries in the post-war period seems to be unrelated to growth in income or improvements in material living conditions. To a large extent, there is still no consensus on the specific factors responsible for these gains. Here, we argue that much can be learned about the nature of life expectancy changes by comparing patterns of mortality reductions within and across countries. We find that, in the case of Brazil, improvements in education and public health infrastructure can explain most of the changes in life expectancy that were not related to improvements in income.

The structure of the remainder of the paper is outlined as follows. Section 2 describes the dataset used and discusses the recent pattern of changes in life expectancy and life expectancy inequality across Brazilian municipalities. Section 3 summarizes the methodology used to assess the economic value of life expectancy changes and applies it to our dataset. Section 4 discusses the determinants of life expectancy changes across Brazilian municipalities and estimates the role played by education, access to water, and sanitation. Finally, section 5 concludes the paper.

2 Data and Recent Trends

We use a municipality dataset constructed by the Instituto de Pesquisa Econômica Aplicada (IPEA, from the Brazilian Ministry of Planning), based on census files from 1970 to 2000 (IPEAdata, available online from www.ipea.gov.br). Municipalities are the smallest administrative units in the Brazilian political system.[2] The dataset contains a series of variables, including average household income per capita and life expectancy at birth, calculated at the municipality level. A problem with the use of these data across different periods of time is that a large number of new municipalities was created in Brazil following the 1985 re-democratization and the writing of a new constitution in 1988. So the

[2] Each municipality is governed by a mayor and has a chamber of representatives. Brazilian municipalities are analogous to US counties.

number of municipalities in the dataset changes from 3,952 in 1970 to 5,507 in 2000. Typically, this was the outcome of a process were regions of an existing municipality would demand emancipation, as a result of potential benefits from tax collection and redistribution of federal resources (for a thorough discussion, see Shikida, 1999).

We concentrate the analysis on municipalities that already existed in 1970 and ignore the newly created ones. Even though there is a large number of new municipalities (1,555), their importance in terms of population is minimal. The existing municipalities in 1970 account for roughly 90% of the Brazilian population in 2000. Given that most of our analysis is weighted by municipality population, the newly created municipalities should have no impact on the results.[3]

Using this strategy, we generate the data on life expectancy at birth and income per capita presented in Table 1. For comparison purposes, the income data are normalized so that Brazilian income per capita in 1990 corresponds to the value from the Penn World Tables 6.1 (1996 international prices). The numbers presented here can therefore be immediately compared to the international evidence discussed elsewhere. The table contains the mean, standard deviation, minimum and maximum for life expectancy at birth and income per capita in Brazil, for 1970 and 2000.

The changes in the period are substantial. Income per capita increases by 170%, while life expectancy at birth rises by 16 years.[4] The extent of variation at a point in time reflects the high degree of inequality in Brazilian society. In 2000, the minimum and maximum values of life expectancy and income are close to the extent of variation observed among poor and wealthy nations of the world (with the exception of the extreme poverty in Sub-Saharan Africa). Income per capita in 2000 ranges from $986 in a municipality in the poor state of Alagoas (Northeast) to $25,018 in a municipality in the state of São Paulo (Southeast). Life expectancy at birth ranges from 55.2 years in a municipality in Maranhão (Northeast) to 78.2 in another municipality in São Paulo.

Despite the high degree of inequality at a point in time, and the persistence of income inequality at the individual level, the dispersion in income and health across Brazilian municipalities was reduced. Table 2 calculates several inequality measures for income per capita and life expectancy at birth across Brazilian Municipalities, in 1970 and 2000. By any measure, inequality in income and life expectancy decreases considerably. The regression to the mean coefficient implies that a municipality 100% richer in 1970 experienced income gains on average 16% lower in the following 30 years. In the case of health, municipalities with life expectancy 10 years higher in 1970 experienced gains in life expectancy on average 3.7 years lower between 1970 and 2000.

It is important for our later discussion to highlight some patters that arise from this table. First, inequality in life expectancy is lower across Brazilian municipalities than across countries. According to any of the measures used, the extent of life expectancy inequality in 2000 within Brazil is only 40% of that observed across countries (comparing numbers from Table 2 with the results presented in Becker et al, 2005). On the other hand, the degree of regression to the mean in life expectancy and the relative reduction in inequality within Brazil are lower than those observed across countries between 1960 and 1990 (we use this period for comparison because, after 1990, the effects of AIDS in Sub-Saharan Africa take over the trend of mortality inequality across countries). The different indexes of life expectancy inequality across Brazilian municipalities are reduced between 40% and 46% in the thirty years in question, while the degree of regression to the mean is -0.37. Across countries, between 1960 and 1990, the different indexes of inequality are reduced between 47% and 57%, and the regression to the mean coefficient is -0.61.

[3] For the period between 1970 and 1990, when roughly one-third of the new municipalities had already been created, data are available for "minimal comparable areas," which are geographically defined areas kept constant throughout the period. Results obtained with the strategy described in the text for the period between 1970 and 1990 are virtually identical to those obtained using the "minimal comparable areas".

[4] This dataset generates average income and life expectancy numbers somewhat different from the ones obtained from the aggregated datasets widely used (such as the World Development Indicators and the Penn World Tables). Life expectancy in the municipality data is lower than in the aggregate data in 1970 and higher in 2000. In the case of income, the growth rate in the period is higher in the municipality data. The specific values for income come from the fact that we normalize the data so that income per capita in 1990 is equal to the value from the Penn World Tables 6.1 for that same year.

This observation is particularly relevant because the difference in the profile and evolution of life expectancy inequality within and across countries may reveal something about the nature of mortality reductions. If the important factors behind these changes are public health technologies that affect the majority of the population of a country, or at least significant portions of the population in most of the municipalities, benefits should affect similarly the different municipalities and the reduction in inequality should not be too large. Obviously, as long as different technologies affect poor and rich areas differently, this would not be strictly true. Nevertheless, it is still true that the public good aspect of public health interventions can limit the degree of reduction in health inequality within countries, when compared to changes observed across countries.

When compared to international numbers, the evidence from Brazil suggests that reductions in mortality were largely due to improvements that were more homogeneously distributed across the country's municipalities. In principle, improvements in the provision of public health, which had similar impacts in the different regions of the country, may have played an important role in determining the observed gains in life expectancy. We explore this point further by looking at how changes in the relationship between life expectancy and income in Brazil compare to those observed across-countries.

Figure 1 plots the cross-sectional relationship between income per capita and life expectancy at birth for Brazilian municipalities, in 1970 and 2000. Since our focus at this point is on how life expectancy varies within Brazil and how this pattern differs from its variation across countries, rather than on the evolution of life expectancy through time, we renormalize the numbers such that the statistics are strictly comparable to international aggregate data at each point in time (this renormalization applies only to Figures 1 and 2). In other words, income per capita and life expectancy in both years are normalized such that the averages for Brazil in the municipality data correspond to the aggregate numbers from the WDI (for life expectancy) and from the PWT 6.1 (for income per capita adjusted for terms of trade).[5] Therefore, the average levels in the figures correspond to the values observed in the aggregate data, but the relative variation within Brazil corresponds to that observed in the municipality data. Figure 1 shows a shift in the cross-sectional relationship between income and life expectancy that is similar to that observed in cross-country data. In the case of Brazil, for constant levels of income, life expectancy has typically risen by more than 5 years. This means that at least 55% of the improvements in life expectancy in Brazil during these thirty years seem to be unrelated to gains in income per capita. This result is even stronger than the one observed across countries between 1970 and 2000, partly because of the effect of AIDS in Sub-Saharan Africa.

But the pattern observed within Brazil is also different in one particularly important respect. In the relevant range, the relationship between income and life expectancy is much steeper in the international data than in Brazil. Figure 2 explores this point by plotting the logarithmic curves summarizing the relationship between these two variables in Brazil and across countries, for the years 1970 and 2000. In both years, the effect of income on life expectancy at birth is much more pronounced across countries than across Brazilian municipalities. The difference in slope is so large that in both years the two curves end up crossing each other at income levels somewhat above the respective Brazilian income per capita (the curves cross each other at $6,000 in 1970 and $10,000 in 2000). This result is consistent with the idea that health infrastructure – broadly understood – is more homogenous within a country than across countries, so that the income-life expectancy profile within countries is closer to the direct effect of income on health than the cross-country profile. Similar evidence is available for Mexico, where the income life-expectancy profile across states in 1970 is remarkably similar to the one estimated here for Brazilian municipalities, while the 1995 relationship is even flatter than the one observed in Brazil in 2000 (see results in García-Verdú, 2005).

Overall, this evidence points to the fact that a large part of the variation in mortality within countries seems to be associated with factors that have some type of public good dimension and, therefore, affect more or less homogeneously the entire population. This argument supports the idea that changes related to the provision of health infrastructure may have been an important factor determining

[5] In other words, the average levels in the figure correspond to the values observed in the WDI and the PWT 6.1, but the relative variation across municipalities corresponds to the one observed in the municipality level dataset.

the reductions in mortality observed in Brazil. Later on, we estimate explicitly the role of public health infrastructure as a determinant of mortality changes across Brazilian municipalities. But first, in the following section, we evaluate the relative importance of income and mortality in terms of the overall improvements in welfare observed in the period. The section starts by discussing the methodology used in the exercise, and then applies it to the data presented here. Though being responsible for an important fraction of overall gains in welfare in Brazil, improvements in life expectancy have not contributed to reduce welfare inequality across municipalities. This result is in stark contrast with the inequality reducing role of life expectancy noticed in the cross-country literature (see, for example, Bourguignon and Morrison, 2004 or Becker et al, 2005).

3 Welfare Gains from Mortality Reductions

3.1 Methodology

The methodology used in this section is a simplified version of that proposed by Becker et al (2005). Consider the indirect utility function $V(Y,T)$ of an individual with lifetime T and lifetime income Y:

$$V(Y,T) = \max_{\{c(t)\}} \int_0^{\mathrm{T}} \mathrm{e}^{-\rho t} u(c(t))dt \quad \text{subject to} \quad Y = \int_0^{\mathrm{T}} \mathrm{e}^{-rt} y(t)dt = \int_0^{\mathrm{T}} \mathrm{e}^{-rt} c(t)dt, \qquad (1)$$

where $y(t)$ is income at age t, $c(t)$ consumption at t, r is the interest rate, and ρ is the subjective discount factor. This budget constraint assumes the existence of perfect capital markets.

Now consider a given individual at two points in time, with lifetime income and life expectancy denoted by Y and T, and Y' and T' respectively. We are interested in the infra-marginal income $W(T,T')$ that would give a person the same utility level observed in the second period, but with the life expectancy observed in the first period:

$$V(Y'+W(T,T'),T) = V(Y',T'). \qquad (2)$$

Income per capita can be used to measure material improvements only with a set of assumptions that justify using a single number to portray changes in a country's welfare. Similar simplifying assumptions are needed here to measure the monetary value equivalent to certain gains in life expectancy. More precisely, to use the model with commonly available income per capita and life expectancy statistics for a given municipality and year, we define a *hypothetical life-cycle individual*. This is a representative individual who receives the municipality's income per capita in all years of life and lives to the age corresponding to the municipality's life expectancy at birth. In order to implement this concept in a simple way, we assume that the subjective discount rate is equal to the interest rate ($\rho = r$), so that optimal consumption is constant and equal to the constant flow of income ($c(t) = c = y$). In this case, the indirect utility function can be expressed in terms of yearly income y as:

$$V(y,S) = u(y)A(T) \qquad (3)$$

where $A(T) = (1 - e^{-rT})/r$. Define $w(T,T')$ as the yearly – as opposed to lifetime – income that measures the gain in longevity in a manner similar to before. Therefore, w satisfies

$$u(y'+w(T,T'))A(T) = u(y')A(T'). \qquad (2')$$

In this context, the monetary value of the overall gain in welfare observed in the period, when measured in terms of yearly income, can be denoted as $(y' - y) + w$. The equivalent lifetime value is simply the present discounted value of this annual flow of income. And the contribution of health to the overall gain in welfare is the fraction $w/[(y' - y) + w]$.

If we can invert the instantaneous utility function $u(.)$, w can be written as:

$$w = u^{-1}\left[\frac{u(y')A(S')}{A(S)}\right] - y'. \qquad (4)$$

The interpretation of w in this context is straightforward. For a given municipality at a point in time, it tells us the value that an individual being born in that moment – earning the average income of the municipality in every period of life and living with certainty to an age equal to the municipality's life expectancy at birth – would attribute to a change in life expectancy from T to T'. By definition, w measures this value as a yearly flow of income.

As stressed by Rosen (1988), two dimensions of the instantaneous utility function affect the willingness to pay for extensions in life expectancy. The first is the substitutability of consumption in different periods of life, i.e. the inter-temporal elasticity of substitution, and the second is the value of being alive relative to being dead. We calibrate the following functional form for the instantaneous utility function to capture these two different dimensions:

$$u(c) = \frac{c^{1-1/\gamma}}{1-1/\gamma} + \alpha . \tag{5}$$

The parameter α determines the level of annual consumption at which the individual would be indifferent between being alive or dead, arising from the normalization of the utility of death to zero. If the inter-temporal elasticity of substitution γ is larger than 1, then α is negative. With expression (4) and this functional form, we obtain a closed form solution for w.

The set of parameters (α,γ,r) needed to compute w can be calibrated from other parameters more commonly estimated in the "value of life" and consumption literatures. More precisely, we have that $\alpha = c^{1-1/\gamma}\left(\frac{1}{\varepsilon} - \frac{1}{1-1/\gamma}\right)$, where $\varepsilon = \frac{u'(c)c}{u(c)}$ is the elasticity of the instantaneous utility function, often discussed and estimated in empirical studies of compensating differentials for occupational mortality risks (see Murphy and Topel, 2003, for example).

We stick to the same calibration suggested by Becker et al (2005), where $\gamma = 1.25$ and $\alpha = -16.2$.[6] As the authors, we also assume the annual interest rate r to be 0.03. In the case of Brazil, these calibrated parameters lead to an implicit value of a statistical life equal to roughly \$310,000. Corbi et al (2006) obtain estimates of the value of a statistical life in Brazil ranging from \$270,000 to \$1,700,000 (expressed in 1996 dollars adjusted for terms of trade). Therefore, our calibrated parameters imply a value of a statistical life that is well in the lower range of available estimates for Brazil. Similarly, our implicit value of a statistical life is also in the lower range of estimates available for other developing countries, such as India, South Korea and Taiwan (see discussion in Viscusi and Aldy, 2004). If anything, our calculations will give conservative estimates of the value of changes in life expectancy.

The calibrated values of the parameters seem to do a good job in describing the preferences of countries at different levels of income. As noted by Becker et al (2005), the functional form adopted is extremely flexible, so that the income-elasticity of the willingness to pay for gains in life expectancy changes substantially with income. In this sense, as the evidence discussed above confirms, the calibration does not impose a willingness to pay value that does not belong to less-developed countries. If we look at the income-elasticity of the marginal willingness to pay for life extensions, it actually varies from 1.2 for average levels of income per capita (around \$10,000 in 2000), to 1.9 and 3.8 for, respectively, \$1,000 and \$500. Therefore, the functional form adopted is flexible enough to identify underlying preference parameters that, in principle, can be used at different income levels.

3.2 Results

The results are presented in Table 3, organized by state averages (weighted by municipality population). Statistics for life expectancy and income are presented for 1970 and for the variation between 1970 and 2000. The last three columns contain the value of life expectancy gains measured in annual income, the net present value of these gains, and the share of these gains in the total welfare improvements observed in the period.

As noted before, there were substantial improvements in both income and life expectancy in Brazil between 1970 and 2000. The table shows that the welfare gains derived from life expectancy improvements were comparable in magnitude to the gains derived from income growth. The share of health in the total gains in welfare varies from 22% to 35%. As in the cross-country case, initially poorer regions tended to have a larger fraction of the overall welfare gains attributable to health. But, in this case, the dispersion in the magnitude of life expectancy changes is much smaller than that observed

[6] With the calibrated parameters, an individual with annual income equal to \$353 would be indifferent between being alive or dead. The only values of the GDP per capita variable (adjusted for terms of trade, *rgdptt*) in the PWT 6.1 dataset below \$353 are those for the Democratic Republic of Congo between 1994 and 1997.

across countries. Life expectancy gains in the period varied from 13 to 22 years, with the vast majority of states being in the even narrower range between 13 and 17 years. If it is true that public health infrastructure is more homogeneous within a country than across countries, the differential behavior of mortality across countries and across Brazilian municipalities supports the idea that public goods may have been an important factor determining the recent gains in life expectancy.

As in the international case, the income dimension is an important determinant of the absolute value of life expectancy improvements. The highest values of life expectancy gains – as measured by yearly income – are around $3,000 and are observed in states that were relatively wealthy in 1970 (Distrito Federal, Rio de Janeiro, and São Paulo). These, as well as other Southern Brazilian states (Rio Grande do Sul and Santa Catarina), reach the end of the period with life expectancy numbers above 70 years, close to the levels currently observed in some developed countries. In any case, for all the different regions of the country, gains in life expectancy represented a significant share of the welfare improvements registered between 1970 and 2000. On average, they increase the estimated gains in welfare by roughly 39%, when compared to the growth in income per capita alone.

Nevertheless, the pattern of initial income inequality, and of homogeneous gains in life expectancy, is such that the reduction in life expectancy inequality does not affect substantially the evolution of welfare inequality. Table 4 calculates the same indexes of inequality presented in Table 2 for our measure of "full-income." This measure is defined as the income level that would have been observed in 2000 if all the welfare improvements between 1970 and 2000 had taken the form of income growth. It represents the income gain corresponding to the overall improvements in welfare in the period. Table 4 shows that the evolution of "full-income" inequality between 1970 and 2000 is remarkably similar to the evolution of income inequality. This is possible because, despite a reduction in life expectancy inequality, the value of changes in life expectancy is higher for relatively wealthier municipalities. Therefore, contrary to the cross-country case, life expectancy changes did not contribute to reduce overall welfare inequality across Brazilian municipalities. A high degree of initial income inequality, coupled with a more or less homogeneous gain in life expectancy, leads to a situation where mortality reductions have an important impact on welfare levels, but no significant impact on welfare distribution.

4 The Determinants of Mortality Reductions

4.1 Previous Evidence and Methodology

Previous papers have analyzed the determinants of mortality variation across regions of Brazil, finding important roles for some dimensions of public health provision. Merrick (1985) uses census and household survey data between 1970 and 1976 to track down the effects of an extensive effort undertaken by the Brazilian government in the early 1970's to improve urban environmental conditions (PLANASA), through better water supply and sanitation. He finds that parents' education and access to piped water were the factors most closely related to child mortality both in 1970 and 1976. Particularly, access to piped water explained about one-fifth of the regional differentials in child mortality. Interestingly, he also shows that improved and increased water supply attenuated mortality differentials associated with education and income (effect of water stronger among low income groups).

Macinko et al (2005) use a state-level panel with data between 1990 and 2002 to evaluate the impact of a family health program on mortality. The program (Programa Saúde da Família) was largely based on preventive care, but evidence shows that family inclusion also affected rates of breastfeeding and immunization, and improved maternal management of diarrhea and respiratory infections. It was particularly effective in reducing deaths attributable to diarrhea. They also show that access to water and female literacy were closely related to mortality across Brazilian states. In their analysis, access to water and female literacy were particularly important determinants of mortality in the poorest regions of the country (North and Northeast), and the effect of family health programs was three times larger in these same regions.

Finally, Alves and Belluzzo (2004) find that education and sanitation were the main determinants of changes in child mortality between 1970 and 2000. Their study analyzes Brazilian municipality data over a period when substantial reductions in child mortality took place. But they focus exclusively on child mortality and do not distinguish between the effects of sanitation and access to clean water. In addition, their treatment of the dynamic panel and of other independent variables is not fully satisfactory, leading to estimates that are likely to be biased and inconsistent.

As Alves and Beluzzo (2004), we analyze the period between 1970 and 2000 and make use of municipality level data. But we look at life expectancy instead of child mortality and extend the analysis in several different ways. First, we explore the independent roles of sanitation and access to clean water, while they do not distinguish between these two variables. Second, we deal with the dynamic panel in a more appropriate way and account for a broader set of controls, some of which are likely to be correlated with the variables of interest and with life expectancy itself. And finally, using the representative agent results from the previous section, we estimate the economic value of improvements in sanitation and access to water and reductions in illiteracy rates.[7]

From the same municipality dataset discussed before, we obtain data on: percentage of households with access to piped water connected to the public water system; percentage of households with access to sanitation connected to the public sewer system; percentage of illiterate people in the population; and degree of urbanization, summarized by the fraction of population residing in urban areas.[8] Changes in public health infrastructure and education since 1970 have been quite substantial. The proportion of households with access to water connected to the public water system increased from 15% in 1970 to 63% in 2000, while the percentage of households with sanitation connected to the public sewer system raised from 5% to 28%. At the same time, the percentage of illiterate people in the population was reduced from 44% to 21%. For illustrative purposes, Table 5 presents the pair-wise correlation between the variables of interest.

The main limitation of the dataset is that it leaves out early childhood immunization and access to medical services, which are potentially important determinants of mortality and are likely to have changed substantially during the period. We therefore include income per capita and urbanization as additional controls in the analysis, to take into account factors known to be correlated to these variables and also to changes in mortality. These include, among others, nutrition, access to public medical care and, to some extent, immunization coverage. As long as populations in wealthier or more urbanized municipalities have better medical support or easier access to services, we will be partly controlling for these factors. Nevertheless, we keep the limitations of the data in mind and come back to this discussion when presenting the results. All municipalities for which these variables are available for 1970, 1980, 1990, and 2000 are included in the analysis.

Our goal is to estimate the impact of each of these factors on the changes in life expectancy observed between 1970 and 2000. Therefore, we adopt the following baseline specification:

$$life\ exp_{i,t} = \alpha_0 + \alpha_1 . life\ exp_{i,t-10} + \beta . X_{i,t} + \varepsilon_{i,t}, \qquad (6)$$

where i refers to municipality and t to time period. $X_{i,t}$ is a vector of municipality characteristics including the variables of interest (access to water, sanitation and illiteracy rate) and the control variables (natural logarithm of income per capita and urbanization rate). We include a lagged dependent variable in the baseline specification to account for the sluggish response of health to changes in health inputs, given that health outcomes in a certain period depend on the stock of health human capital accumulated before (as suggested, for example, by Grossman, 1972).

As in the cross-country context, there are two main concerns in this type of estimation: unobserved municipality specific characteristics and endogeneity of right hand side variables. In order to address the first of these problems, and to capture nation wide changes, we allow for both municipality and time specific factors in the random term, such that $\varepsilon_{i,t} = \theta_i + \gamma_t + u_{i,t}$. But fixed-effect estimators are known to be inconsistent in the presence of lagged dependent variables, as in the case of equation (6). To

[7] Though Alves and Belluzzo (2004) do not report Sargan test statistics, the results obtained here suggest that their dynamic specification does not account for endogeneity in an adequate way (more on this on footnote 10). In addition, they do not control for the degree of urbanization of the municipality, which is likely to be related to access to medical and other types of public health services (immunization, public clinics, etc).

[8] Notice that the access to water and sanitation variables are defined differently from the ones usually available from the World Development Indicators. In the latter, the variable considers access to treated water or improved sanitation, even when these are not directly connected to the public system. Therefore, the variables used here have means significantly lower than the ones from this dataset.

deal with the inconsistency of the fixed-effect estimator in such setting and to address the issue of endogeneity of the independent variables, we resort to the Arellano-Bond dynamic panel estimator (Arellano and Bond, 1991).

There are also a couple of reasons why one should be concerned about the endogeneity of the $X_{i,t}$ variables here. First, non-observed municipality-specific shocks may lead to simultaneous changes in all of these variables, even in the absence of any causal relationship between them. Specifically, development may bring together increases in life expectancy, income, access to water, sanitation, urbanization, and education. As mentioned before, we partly control for this possibility by including income per capita and degree of urbanization as independent variables in the regression. Still, depending on the correlation and on the degree of measurement error in the different variables, there may be some spurious correlation left. Second, it is reasonable to expect that some of these variables may respond directly to life expectancy. This would be the case if governments responded to poor health conditions in certain areas by constructing new water and sewer systems. Since we are dealing with very long time lags between observations, this may well be the case. This type of reverse causality would lead to underestimation of the impact on life expectancy of exogenous changes in access to water and sanitation.

The use of the Arellano and Bond (1991) dynamic panel technique deals with this problem to the extent that it does not explore simultaneous correlations between endogenous and exogenous variables. The method estimates the dynamic fixed-effects model by differencing the data, and then using lagged levels of the dependent, predetermined, and endogenous variables to instrument for the differences in the right hand side variables (when there are strictly exogenous variables, their lagged differences are also used as instruments). We treat the variables in $X_{i,t}$ as endogenous and apply the standard procedure for this case (use $t-2$ lagged levels as instruments for the endogenous variables).[9]

4.2 Results

The results of the estimation are presented in Table 6. For illustrative purposes, the first two columns present the OLS regression in the pooled data and the fixed-effects estimator. The third column presents the standard Arellano-Bond estimator with one lag of the dependent variable included in the right-hand side. The comparison of the coefficients of $Life_{-1}$ in the OLS, fixed effects, and Arellano-Bond estimators gives support to the use of the dynamic model: in such setting, the OLS estimate should be biased upward and the fixed-effects should be biased downward (Bond, 2002). But the standard Arellano-Bond estimator with only one lag of the dependent variable does not satisfy the Sargan test of over-identifying restrictions: the test rejects the hypothesis that the excluded instruments do not affect life expectancy directly. Therefore, we include a second lag of the dependent variable ($Life_{-2}$) in the specification, as shown in the last column of Table 6, and use three-period lagged levels as instruments.[10] In the specification in the last column, we cannot reject the hypothesis that the instruments are exogenous. This is our preferred specification.

Notice that, as expected, the addition of fixed effects and the increasing exogeneity of the instruments are both associated with increases in the estimated impact of access to water and sanitation on life expectancy. This should be the case if one thinks that the main problem of endogeneity is related to the response of governments to poor health conditions in certain municipalities (through improvements in public health infrastructure and services). The coefficients on the other explanatory variables also tend to increase when one additional lag of the dependent variable is included in the regression and the exogeneity of the instruments is not rejected.

Quantitatively, the results are very expressive. A fifty percentage points increase in the fraction of households with access to treated water is associated with a 2.5 year gain in life expectancy at birth, while

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[9] Mobarak et al (2004) show that provision of health services in Brazil depends to some extent on political considerations. This suggests that there is a dimension of change in our variables of interest that is somewhat exogenous to the health conditions faced in different areas, and therefore can be used to identify the effect of public health infrastructure.

[10] Alves and Beluzzo (2004), when analyzing the determinants of child mortality, do not perform tests of over-identifying restrictions. Their preferred specification uses one lag of the dependent variable. The results obtained here suggest that, if the dynamic structure of life expectancy and child mortality are similar, their specification is likely to be inadequate to deal with the dynamic characteristics of the data. Together with the fact that they do not distinguish between access to water and sanitation, and do not control for urbanization, this may explain the relatively small quantitative effect that they find.

the same increase in the fraction of households with access to sanitation is associated with a 1.4 year gain. A reduction of fifty percentage points in the illiteracy rate leads to an increase of 5.4 years in life expectancy at birth. Income per capita is also an important determinant of the changes in life expectancy, with a doubling of income being generally associated with a 4.8 years gain in life expectancy.

In terms of the extent of variation actually observed in the sample, the short term impact of income, access to water, sanitation, and illiteracy can explain 71% of the within municipality variation in life expectancy. According to the coefficients in column (4), 33% of the within municipality reduction in mortality can be attributed to the immediate impact of increases in income, while 38% can be attributed to improved access to water, sanitation, and reductions in illiteracy rates (16%, 6%, and 16%, respectively). The short run impact of these same variables explain 93% of the overall variation in life expectancy, with 42% attributed to income per capita and 51% attributed to access to water (17%), sanitation (9%), and illiteracy (25%).

Amazingly enough, our results related to the role of income in determining changes in life expectancy are remarkably similar to those obtained in a series of cross-country studies (see, for example, Preston, 1980, Palloni and Wyrick, 1981, and Heuveline, 2001). These studies have generally found that, during the post-war period, changes in income and nutrition can explain at most 50% of the variation in mortality across countries. We find here that income per capita explains 42% of the variation in mortality across Brazilian municipalities between 1970 and 2000. In addition, we show that changes in education and public health infrastructure explain almost all the residual variation in life expectancy. Preston (1980) hypothesized that the estimated effect of income in the cross-country context also captured variations in provision of public health infrastructure associated with economic development. Therefore, he excluded these factors from what he called “structural” determinants of life expectancy (those not associated with changes in income per capita). Our results show that, in the within country context, there is a significant dimension of change in public health infrastructure that is orthogonal to changes in income. Even though the correlation between income and public health infrastructure is likely to be stronger across than within countries, it is still likely that some independent variation takes place in this dimension also in the cross-country context. Therefore, public health infrastructure may be an important factor explaining the shift in the income-life expectancy profile observed both within and across countries.

Some limitations of our results should still be kept in mind. In this respect, the main problem is the absence of any measure of the presence and extent of immunization in different municipalities. As suggested before, this is likely to have been an important factor determining the reductions in mortality observed in Brazil.[11] If the implementation of immunization programs at the municipal level was correlated with expanded investments in health infrastructure or education, it is possible that our independent variables are partly capturing the effects of changes in immunization rates and other medical services. We control for this possibility to the extent that these variables may be related to the income level and degree of urbanization of different areas. In addition, the Arellano-Bond results suggest that the endogeneity problem in the OLS estimation is most likely related to the endogenous response of governments to differential health conditions across the country, instead of being related to the effect of omitted variables. Still, it is impossible to address this issue explicitly without data on immunization rates per municipality, which are currently unavailable. The implementation of large-scale immunization programs was an important event in the history of public health in Brazil, and the direct estimation of its effects certainly deserves further attention.

In any case, the evidence supports the idea that provision of public goods related to education and health was a major factor determining the gains in life expectancy observed between 1970 and 2000. With the results from the previous section on the monetary value of gains in life expectancy, we can estimate the per capita value of the improvements in health infrastructure for our representative individual. Similarly, we can also estimate the value of reductions in illiteracy rates. These are based exclusively on the impacts of these variables on mortality, and therefore ignore several other benefits that may derive from them (such as reductions in morbidity and improvements in the stock of human capital,

[11] Countrywide, between 1980 and 2000, immunization rates (children under 1 year) for DPT increase from 46% to 92%, while immunization rates for measles increase from 62% to 98% (World Bank, 2005).

for example). The results imply that, for our representative individual, improvements in access to water and education had a lifetime value of $7,500 each, while improved sanitation had a value $2,800. When compared to the income per capita in Brazil in 1970, these are quite substantial numbers. They imply that an individual born in 1970 would be willing to pay the following proportions of one year's income in order to finance the improvements registered between 1970 and 2000: 248% for either access to water or education, and 93% for sanitation (lifetime values). Since there are many other dimensions through which these same factors increase welfare, these are likely to be lower bounds for the true economic value of the observed improvements in public health infrastructure and education.

5 Concluding Remarks

This paper shows that the income-life expectancy profile across Brazilian municipalities has been shifting consistently throughout recent decades. For constant levels of income, life expectancy rose by more than 5 years between 1970 and 2000. Though this evidence reproduces the pattern observed internationally, the income-gradient of life expectancy within Brazil is much less pronounced than that across countries. Similarly, the gains in life expectancy have been more homogeneously distributed across municipalities than across countries. The paper suggests that much can be learned about the nature and the determinants of recent mortality reductions by analyzing the differences in the pattern of life expectancy changes across and within countries. The descriptive evidence is consistent with reductions in mortality driven by country-wide changes, possibly associated with the diffusion of technologies incorporated in health related public goods.

We then go on to explicitly estimate the determinants and the welfare implications of these gains in life expectancy. We calculate that, between 1970 and 2000, reductions in mortality had a welfare value corresponding to 39% of the observed growth in income. In a dynamic panel setting, we show that most of these gains can be explained by changes in income per capita, illiteracy rates, and access to treated water and sanitation. For the representative individual, the lifetime present value of improvements in access to water was in the order of $7,500, while the value of improvements in sanitation was around $2,800. Similarly, the life expectancy benefit generated by reductions in illiteracy rates had a present value of $7,500.

Nevertheless, given that initial income inequality across Brazilian municipalities was very high and that life expectancy gains were more or less homogeneous, changes in mortality did not contribute to reduce overall welfare inequality. In Brazil, life expectancy had a significant impact on the level of welfare, but it did not play the same role in reducing welfare inequality as it did across countries.

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Table 1: Descriptive Statistics, Income and Life Expectancy, Brazil, 1970-2000

	Income per Capita		Life Expectancy	
	1970	2000	1970	2000
Mean	3,013	8,160	52.9	69.3
Std Dev	2,280	4,676	4.8	3.7
Min	271	986	36.7	55.2
Max	11,050	25,018	67.8	78.2

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Life expectancy is life expectancy at birth. Statistics weighted by municipality population.

Table 2: Evolution of Cross-Municipality Inequality in Income and Life Expectancy, Brazil, 1970-2000

	Income per Capita		Life Expectancy	
	1970	2000	1970	2000
Relative Mean Dev	0.3035	0.2329	0.0370	0.0201
Coeff of Variation	0.7566	0.5730	0.0903	0.0539
Std Dev of Logs	0.7615	0.6695	0.0927	0.0556
Gini Coeff	0.4130	0.3289	0.0513	0.0290
Regression to the Mean over Previous Date		-0.1623 (p-value=0.00)		-0.3713 (p-value=0.00)

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Life expectancy is life expectancy at birth. Inequality measures weighted by municipality population (abstracting from within inequality). Regression to the mean is the coefficient of a regression of the change in the variable over the period on its initial level (natural logs used in the income regressions; weighted regressions).

Table 3: Income Life Expectancy and Value of Life Expectancy Gains; 1970-2000; Brazilian States

State	Life exp 1970	Income per capita 1970	Gain in life exp, 1970-2000	Gain in income, 1970-2000	Value of life exp gain in yearly inc.	NPV of life exp gains	Health share in welfare gains
Acre	50.8	1,944	15.9	2,586	931	24,365	26%
Alagoas	48.4	1,421	15.5	1,613	626	16,086	28%
Amapa	54.9	2,310	13.0	3,584	1,055	28,379	23%
Amazonas	51.4	2,104	14.6	1,569	714	18,828	31%
Bahia	48.4	1,713	16.1	1,994	1,004	25,602	33%
Ceara	49.6	1,239	17.8	2,310	1,018	26,061	31%
Distrito Federal	57.2	5,238	13.2	10,628	3,266	89,298	24%
Espirito Santo	52.9	2,006	15.5	5,170	1,795	47,395	26%
Goias	53.2	2,144	16.3	4,959	1,704	45,247	26%
Maranhao	46.2	1,303	15.0	1,164	567	14,272	33%
Mato Grosso do Sul	55.4	2,412	14.4	4,266	1,338	35,994	24%
Mato Grosso	52.0	1,975	16.9	4,569	1,720	45,166	27%
Minas Gerais	52.7	2,235	17.6	4,429	1,759	46,611	28%
Para	53.0	1,944	15.8	2,446	920	24,510	27%
Paraiba	46.5	1,104	16.1	2,206	892	22,428	29%
Parana	53.8	2,390	15.8	4,830	1,702	45,420	26%
Pernambuco	48.4	1,771	18.4	2,911	1,404	36,026	33%
Piaui	49.6	959	14.7	2,052	678	17,374	25%
Rio de Janeiro	54.4	5,609	15.3	5,958	2,872	77,159	33%
Rio Grande do Norte	44.9	1,246	21.9	2,639	1,452	35,978	35%
Rio Grande do Sul	58.2	3,277	13.9	5,914	1,711	46,976	22%
Rondonia	49.1	3,225	16.2	4,179	2,208	56,482	35%
Roraima	52.8	2,171	14.3	5,280	1,676	44,379	24%
Santa Catarina	58.2	2,269	15.4	6,216	1,704	46,595	22%
Sao Paulo	56.7	5,382	14.7	6,554	2,564	69,856	28%
Sergipe	47.3	1,452	16.4	2,410	1,157	29,310	32%
Tocantins	48.2	1,320	17.1	2,388	972	24,747	29%
Brazil	52.9	3,013	15.9	4,462	1,752	46,762	28%

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Life expectancy is life expectancy at birth. Statistics weighted by 1970 municipality population.

Table 4: Evolution of Cross-Municipality Inequality in Full-Income, Brazil, 1970-2000

	Income per Capita		Full-Income
	1970	2000	2000
Relative Mean Dev	0.3035	0.2329	0.2341
Coeff of Variation	0.7566	0.5730	0.5718
Std Dev of Logs	0.7615	0.6695	0.6816
Gini Coeff	0.4130	0.3289	0.3291
Regression to the Mean over Previous Date		-0.1623 (p-value=0.00)	-0.1486 (p-value=0.00)

Note: Income per capita is GDP per capita in 1996 international prices, adjusted for terms of trade (average 1990 income per capita normalized to the Penn World Tables 6.1 value for Brazil). Full-income is based on the author calculations using life expectancy at birth. Inequality measures weighted by municipality population (abstracting from within inequality). Regression to the mean is the coefficient of a regression of the change in the variable over the period on its initial level (natural logs used in the income regressions; weighted regressions).

Table 5: Correlation across Brazilian Municipalities, 2000

	life	ln(inc)	water	elect	sanit	illit
ln(inc)	0.7858					
water	0.4136	0.6034				
elect	0.5168	0.652	0.5672			
sanit	0.4395	0.557	0.5652	0.4413		
illit	-0.7794	-0.8957	-0.5317	-0.5782	-0.4714	
urb	0.4065	0.6312	0.7848	0.5571	0.5465	-0.5237

Obs.: All correlations significant at 1% significance level; 3,715 observations. Variables are life expectancy at birth, natural logarithm of income per capita, percentage of households with access to piped water connected to the public water system, percentage of household with access to sanitation connected to public sewer system, percentage of illiterate people in the population, and fraction of population residing in urban areas.

Table 6: Determinants of Life Expectancy Changes, Brazilian Municipalities, 1970-2000

	OLS	F.E.	A-B (1)	A-B (2)
$Life_{-1}$	0.6155 *	0.0484 *	0.4151 *	0.3207 *
	0.0062	0.0115	0.0228	0.0350
$Life_{-2}$				0.0397 **
				0.0176
ln(inc)	1.1800 *	0.9232 *	3.3043 *	4.7710 *
	0.0837	0.1309	0.5662	1.0424
water	0.8618 *	1.5561 *	3.5468 *	4.9452 *
	0.1854	0.2488	0.6080	1.1447
sanit	0.3890 *	0.7783 *	1.3175	2.7896 **
	0.0984	0.2230	0.7957	1.1971
illit	-5.5928 *	-1.9597 *	-9.2271 *	-10.8178 *
	0.2878	0.6061	1.0656	2.0071
urb	-1.3420 *	-2.8740 *	-8.2598 *	-6.8908 *
	0.1663	0.3664	1.1982	1.9946
const	18.5985 *	48.9621 *	1.7027 *	-0.9865
	0.7364	1.2344	0.3183	0.5314
R^2	0.89	0.95		
Sargan Test (p-value)			0.00	0.17

Obs.: Standard errors below coefficients; * indicates significance at 1%; ** indicates significance at 5%. All regressions control for period specific dummies. Dependent variable is life expectancy at birth. Independent variables are the natural logarithm of income per capita (1996 int. prices), percentage of households with access to piped water connected to the public water system, percentage of households with access to sanitation connected to public sewer system, percentage of illiterate people in the population, and the degree of urbanization (fraction of population residing in urban areas).

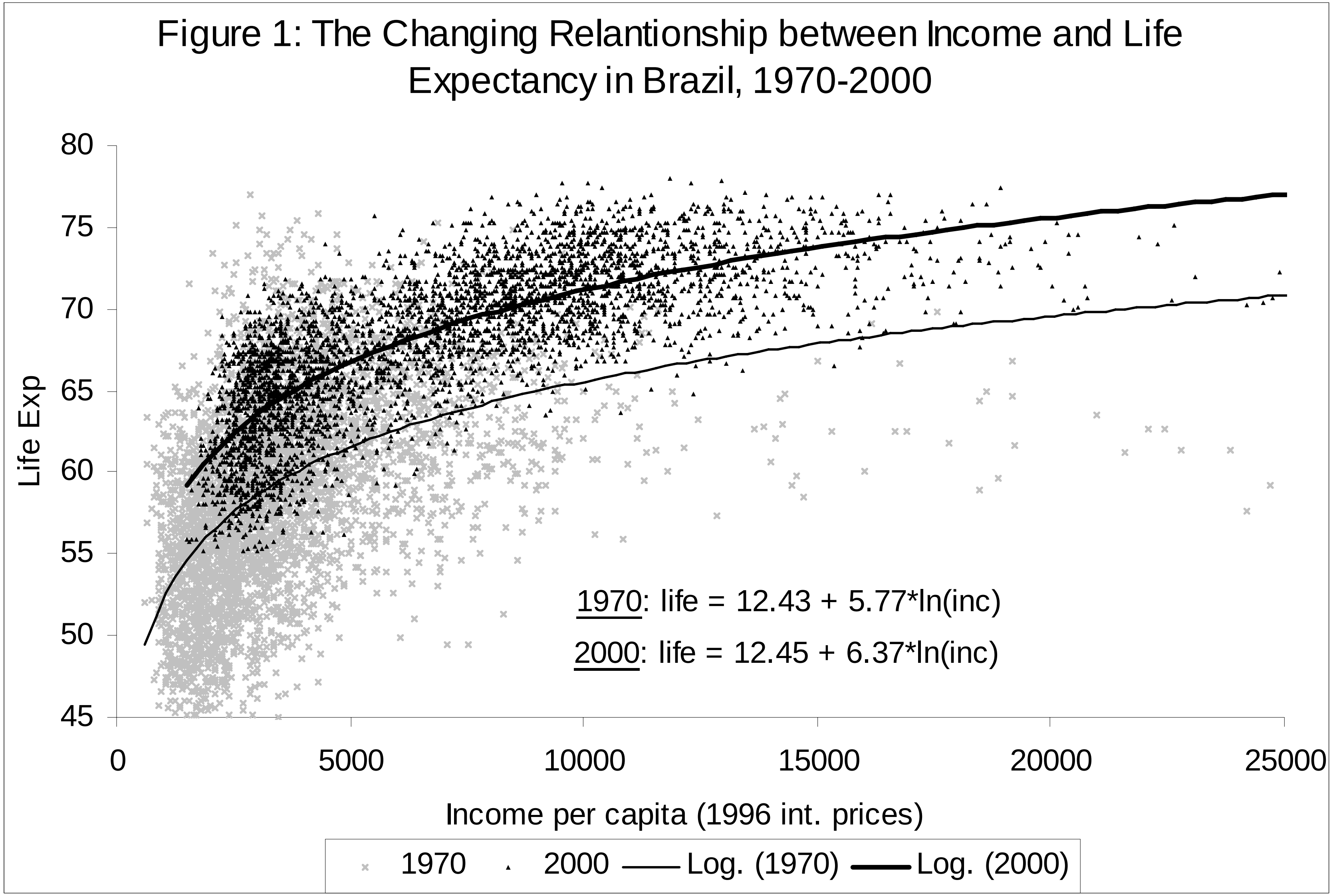
Figure 1: The Changing Relantionship between Income and Life Expectancy in Brazil, 1970-2000
80
75
70
65
60
55
50
45
Life Exp
0
5000
10000
15000
20000
25000
Income per capita (1996 int. prices)
1970: life = 12.43 + 5.77*ln(inc)
2000: life = 12.45 + 6.37*ln(inc)
1970
2000
Log. (1970)
Log. (2000)

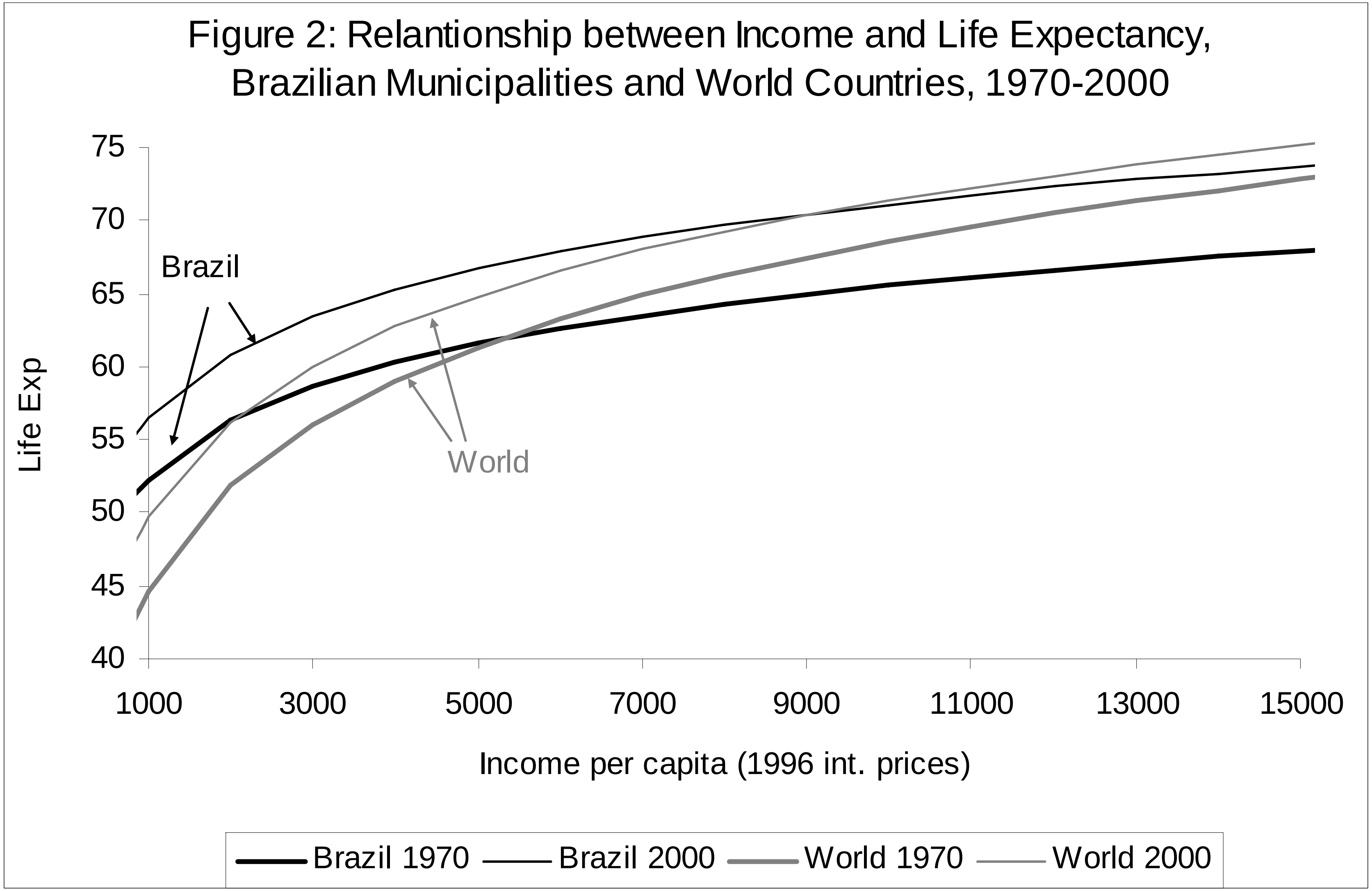
Figure 2: Relantionship between Income and Life Expectancy,
Brazilian Municipalities and World Countries, 1970-2000
75
70
65
60
55
50
45
40
Life Exp
Brazil
World
1000
3000
5000
7000
9000
11000
13000
15000
Income per capita (1996 int. prices)
Brazil 1970
Brazil 2000
World 1970
World 2000